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MACHINE CASTING OF FERROUS ALLOYS

H. R. Larson, et al

Abex Corporation

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May 1975

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H. R. LARSON, B. A. HEYER and C. P. BISWAS
Abex Corporation
Research Center
Mahwah, N. J. 07430

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental ferrous casting machine of 20 lbs. capacity and adaptable to both rheocasting and conventional casting process has been constructed. It is a bottom-pour furnace in which the melting is done under a slightly positive pressure of inert gas and pouring is accomplished by pressuring the furnace chamber. Several problems were encountered during the operation of the furnace, for example, freezing of the metal in the nozzle during pouring, breaking of the stirring paddles,

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20. ABSTRACT (continuation)

and stopper rod during rheocasting, etc. Therefore, the machine is now being redesigned and modified.

FOREWORD

This report covers work done during the period 1 July 1974 - 31 December 1974 under the general title "Machine Casting of Ferrous Alloys". The work was carried out at the Abex Research Center, Valley Road, Mahwah, N.J. 07430, by the principal investigators, H.R. Larson, B.A. Heyer and C.P. Biswas. The work was sponsored by the Defense Advanced Research Projects Agency under ARPA Order No. 2267 and Contract No. DAAG46-73-C-0113 with Dr. E. Wright and Mr. F. Quigley at the Army Materials and Mechanics Research Center as the program technical monitor.

SUMMARY

The work at Abex Corporation on Machine Casting of Ferrous Alloys during this report period has been directed toward construction and operation of an experimental melting and casting machine to evaluate both conventional and rheocasting techniques. The construction of the machine has been completed and several heats of aluminum alloys, both conventional and rheocasting, were made with partial success. Several operational difficulties were encountered during melting and pouring of the melt, e.g., freezing of the melt in the nozzle during pouring, breakage of the stirring paddles and stopper rod, heating of the pressure chamber cover, high resistance to shaft rotation, etc. Therefore, it was necessary to modify and redesign some of the machine components and operations. The redesigning of the machine is in progress now and ferrous castings will be made after it is completed.

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INTRODUCTION

This report is the third describing the work conducted at Abex Corporation on Machine Casting of Ferrous Alloys during the period July 1, 1974 to December 31, 1974. This research program was designed to develop a new technique for a die casting process that will be economically visible for ferrous alloys. Emphasis of the work at Abex is on development of a completely integrated furnace-valve-mold ferrous casting system that will produce quality castings in the five to twenty-five pound class. Our efforts have been directed in three major areas:

(1) Design and fabricate and experimental melting and casting unit.

(2) Determine the feasibility of a magnetohydrodynamic (MHD) valve.

(3) Develop a permanent mold.

During the six month period of research covered by this report, emphasis has been on the fabrication and operation of the experimental casting machine to establish the materials and process parameters for the construction of a full scale automatic casting machine.

PROCEDURES AND RESULTS

As described in earlier reports, our experimental melting and casting machine consists of a 100 KW, 3000 cps induction furnace that is capable of producing 20 lbs. of iron castings in each melting cycle. It is a bottom pour furnace that can be adapted to either conventional casting or rheocasting process. The melting and casting operation take place entirely in an inert atmosphere to minimize slag formation and the pouring is accomplished by pressurizing the furnace chamber. The design details, materials used and operation procedures of this machine were described in the previous two interim reports.*

During this reporting period the construction of the machine was completed and several aluminum alloy heats were made by both conventional casting and rheocasting processes.

The complete assembly of our experimental casting machine is shown in Figures 1 and 2. The induction furnace is enclosed by a stainless steel pressure vessel to facilitate a slightly positive pressure of argon during melting and pressurization of the furnace for pouring the melt. A 3" Y-block mold was used for our test castings. In order to provide a less severe thermal condition for preliminary operations, heats of 356 aluminum base alloy of m.p. 1225°F were made for casting.

The details of the first experimental heat are as follows:

*"Machine Casting of Ferrous Alloys", Technical Reports AMMRC CTR 74-28 (April 1974) and AMMRC CTR 74-56 (September 1974).

Wt. of the charge	- 10 lbs.
Power input for meltdown	- 25 KW
Casting process	- Conventional
Maximum temperature of the melt	- 1400°F
Temperature of pouring	- 1350°F
Metal hold time	- 20 min.
Melting and casting atmosphere	- Air
Pouring	- Bottom pour, operated by stopper rod

The major problem encountered in this heat was the freezing of the melt in the nozzle (alumina tube of 0.5" I.D., 1.5" O.D. and 8" long) during pouring. The preheating of the nozzle seemed to be essential to solve this problem. Therefore, a 20 gage Nichrome wire was wound around the nozzle on the outside with a spacing of 6 turns to an inch for resistance heating. A ceramic insulation coating of Ultra-Temp 516 was used to protect the winding. The nozzle temperature was recorded intermittently during the heat.

Using the preheated nozzle, a second heat was made in the same manner as the first one. Just prior to pouring when nozzle temperature reached about 900°F, the heating coil burnt out and the metal again froze in the nozzle during pouring. The burning was caused by excessive heating of the coil due to high current input (80 volts).

The next step taken was to increase the number of turns to 8 to an inch, use 22 gage wire and apply only 50 volts to the coil. By this a steady temperature of about 950°F was achieved inside the nozzle. A similar heat was made using this preheated nozzle. This time the pouring was successfully accomplished by using a chamber pressure of 5 psi.

A fourth heat was made in which the liquid metal was held in the furnace at 1300°F and the paddles were turned to 100 rpm and the chamber was pressurized to 20 psi. Several leaks in the chamber were detected and they prevented from building any higher pressure. This heat was successful.

The next heat was made for rheocasting. The details are:

Maximum meltdown temperature	- 1350°F
Temperature at which stirring was started	- 1250°F
RPM of the paddles	- 100 (approx.)
Power input during cooling (and stirring)	- 9 KW
Cooling rate during stirring	- 10°F/min.
Temperature of pouring	- 1190°F
Solid fraction at pouring	- 0.5 (approx.)
Nozzle temperature during pouring	- 950°F

This heat was also successful. The micrographs of conventionally cast and rheocast 356 aluminum alloy are shown in Figure 3.

Several other problems were encountered during the furnace operations for the above heats. Therefore it was decided to modify some of the designs to solve these operational difficulties and make the furnace more adaptable to ferrous castings. The problems encountered and the proposed design modifications are discussed below.

(1) Although calculations have shown that the preheating of the nozzle was unnecessary, the metal freezing became a serious problem during pouring. This was probably due to slow leakage and subsequent freezing of the metal in the nozzle during melting and stirring of the melt. In any case, it was decided to enlarge the nozzle diameter and preheat the nozzle to about 2600°F for ferrous castings. But using a resistance heating coil a maximum of 1200°F was reached in the nozzle. Therefore, an induction heating will be used for the nozzle. Due to poor magnetic permeability of alumina nozzles, iso-pressed high density alumina graphite refractory nozzles will be used instead. This is a proprietary material made by Vesuvius Crucible Company and is supposed to have higher resistance to oxidation and erosion by metal than pure graphite. For convenience, the crucible and the nozzle will be made of one piece as shown in Figure 4.

An induction coil of 5-1/2" diameter and 6" length will be used for preheating the nozzle. Since both the melting coil (for the crucible) and the heating coil (for the nozzle) will be required to run at the same time and the power input in these two coils cannot be controlled independently from the same power supply (the power drawn by each coil is dictated by the degree of magnetic coupling in the coil), a separate power source (15 KW, 3,000 cycles MG set) will be used for the heating coil. Since the induction heating coil will be enclosed in the furnace chamber, the pressure vessel has been redesigned to accommodate the heating coil as shown in Figure 5.

(2) Excessive leakage through several connections to the pressure chamber prevented building up of high pressure in the chamber. Use of better seals has improved the pressure build-up. It has been found that a pressure of 20 psi in the chamber will be sufficient for successful pouring during rheocasting of up to 0.6 solid fraction. Therefore, the modified stainless steel chamber will be rated for only 30 psi.

(3) The lid of the pressure chamber appeared to be heated up by the radiation of heat from the molten metal.

Since this heating may be severe during processing of ferrous metals, it was decided to water cool the lid. A water cooling jacket made of stainless steel will be welded on the outside of the lid as shown in Figure 5.

(4) The high purity slip-cast alumina paddles supplied by Norton Company was found to be unsuitable due to their insufficient strength - there was frequent breakage problem. So either (a) silicon-oxy-nitride paddles (made by Norton Company) that are stronger than alumina paddles or (b) a set of closely spaced cylindrical alumina tubes will be used for stirring the melt. These tubes are made by McDanel Refractory Company and used for thermocouple protection tubes.

The alumina tubes will be tried first and in case of their failure, silicon-oxy-nitride will be used. Since these stirring tubes will undergo severe stress during stirring and their strength drops drastically around 2000^{o}F, cylindrical graphite rods will be inserted inside the tubes for reinforcement. The graphite rods will be fastened to the stirring rod holder and the alumina tubes will be glued on to the graphite rods as shown in Figures 6 and 7. The exposed graphite surface will be given a protective coating against oxidation.

(5) In one case the stopper rod broke during the meltdown period. This was caused by the expansion of the plug shaft since it is rigidly fixed at the top end by a push-pull clamp device. In order to allow for free expansion, the plug shaft will be attached to the push-pull clamp through a flexible connector. By this arrangement the stopper rod will close the nozzle by the weight of the shaft and for pouring it will be pulled up by the clamp.

The stopper rods will also be replaced by McDanel's alumina tubes. These hollow tubes will be filled with refractory packing as shown in Figure 8.

(6) The resistance to shaft rotation was high. This was due to the shaft not being perfectly straight and also the improper mounting of the stationary water jacket around the shaft. This problem will be solved by improving all the shaft bearings and redesigning the water jacket support system.

(7) There was an occasion of rise of the liquid metal in the clearance between the center shaft (for operation of stopper rod) and outer shaft (for rotation of the paddles) by capillary action. This was caused by an excessive rise of the meniscus of the liquid metal during meltdown. The entire shaft assembly will be raised about 3" to prevent any metal contact. This will also bring the paddle holder outside the

induction coil and prevent its unnecessary heating up by the induction field. This will require longer stopper rod and stirring rods.

(8) The assembly for lifting the pressure vessel cover and the shaft will be modified to provide a smooth lift with adjustable speeds and also to hold the cover and the shaft in any intermediate position. A larger air cylinder will be installed and also the brass bushings will be replaced by linear ball bearings for the sliding shafts.

(9) A second sight port will be installed on the pressure vessel lid for lighting the inside of the vessel. (See Figure 5).

(10) Three guide rods will be provided on the pressure vessel to guide and align the vessel cover. (See Figure 5).

(11) One relief valve will be installed in the pressure chamber.

(12) Provisions will be made for independent lifting of the cover, shaft and plug rod.

(13) Two thermocouples - one on the crucible wall and the other on the nozzle wall - will be installed to record the crucible and nozzle temperatures. The thermocouple on the crucible wall will be calibrated

against the temperature of the metal inside the crucible so that the temperature of the melt can be estimated during stirring of the melt.

A schematic drawing of the modified furnace assembly is shown in Figure 9. The graphite mold for the test bar will be fastened with the bottom plate of the furnace by four mounting studs. The mold surface will be chromized and plasma sprayed with zirconia.

At the time of writing this report the above modifications are in progress and by the end of June the work is expected to be completed and some experimental heats of ferrous alloys will be run.

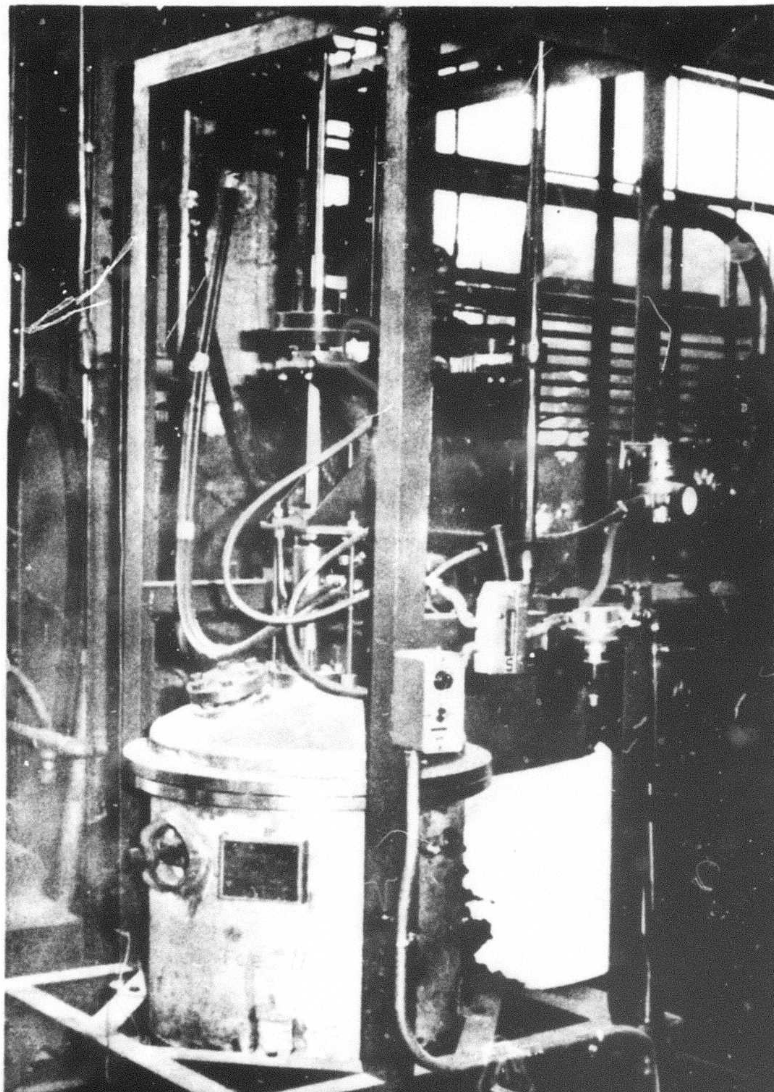


Figure 1. Experimental Melting and Casting Unit

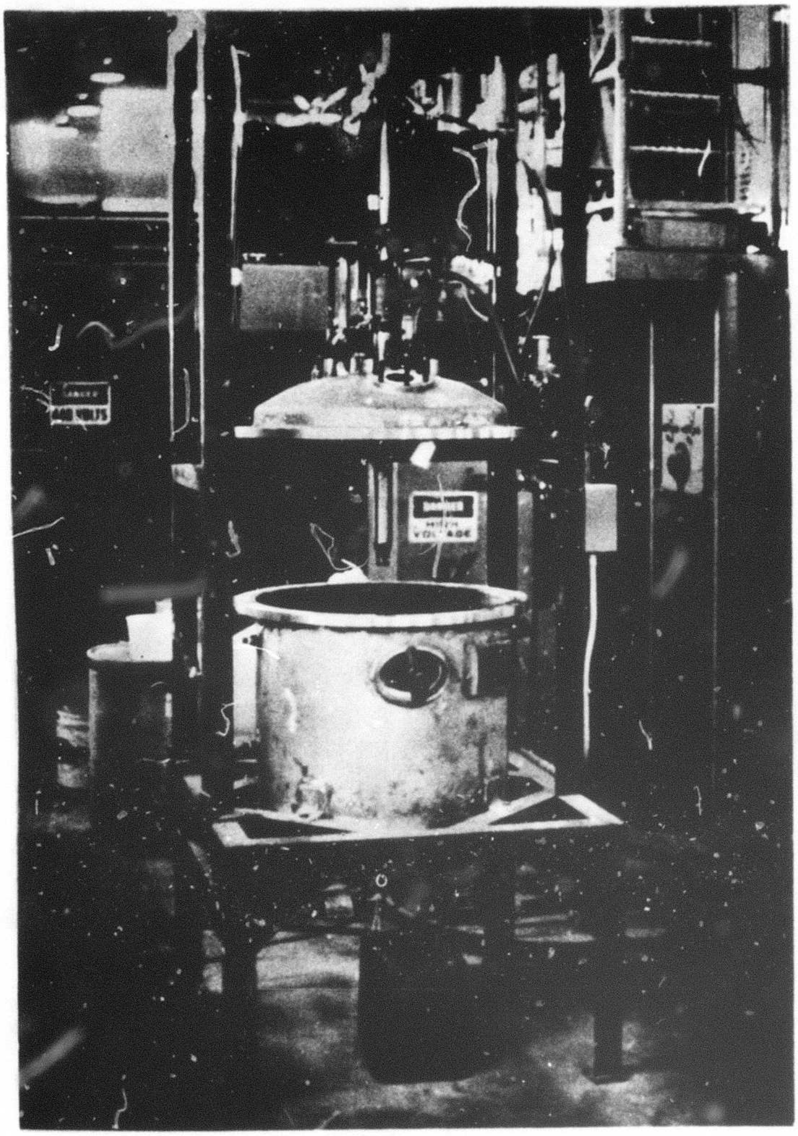
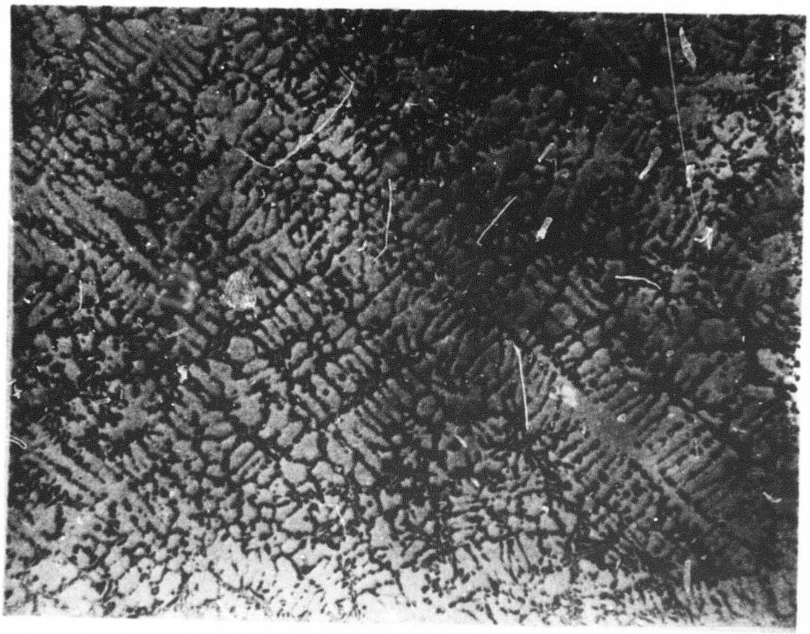
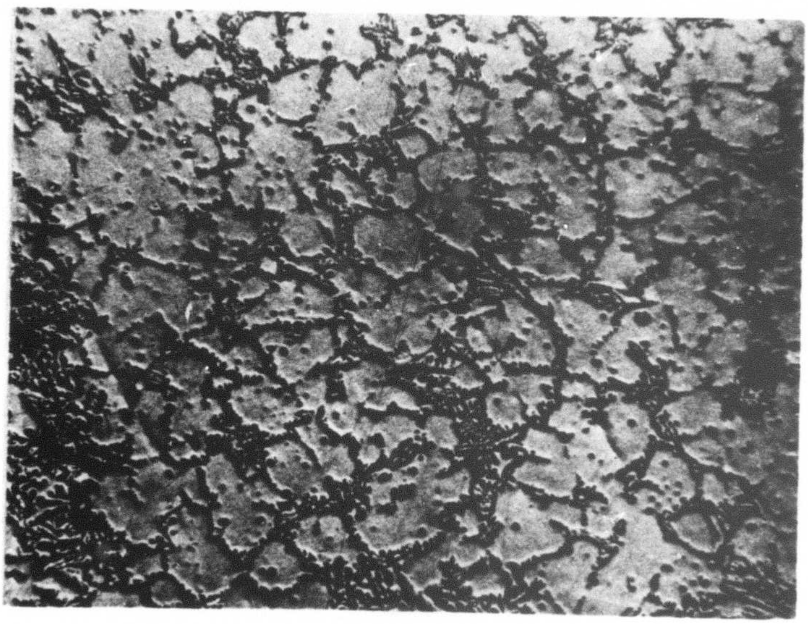


Figure 2. Experimental Melting and Casting Unit



AW116701 50X

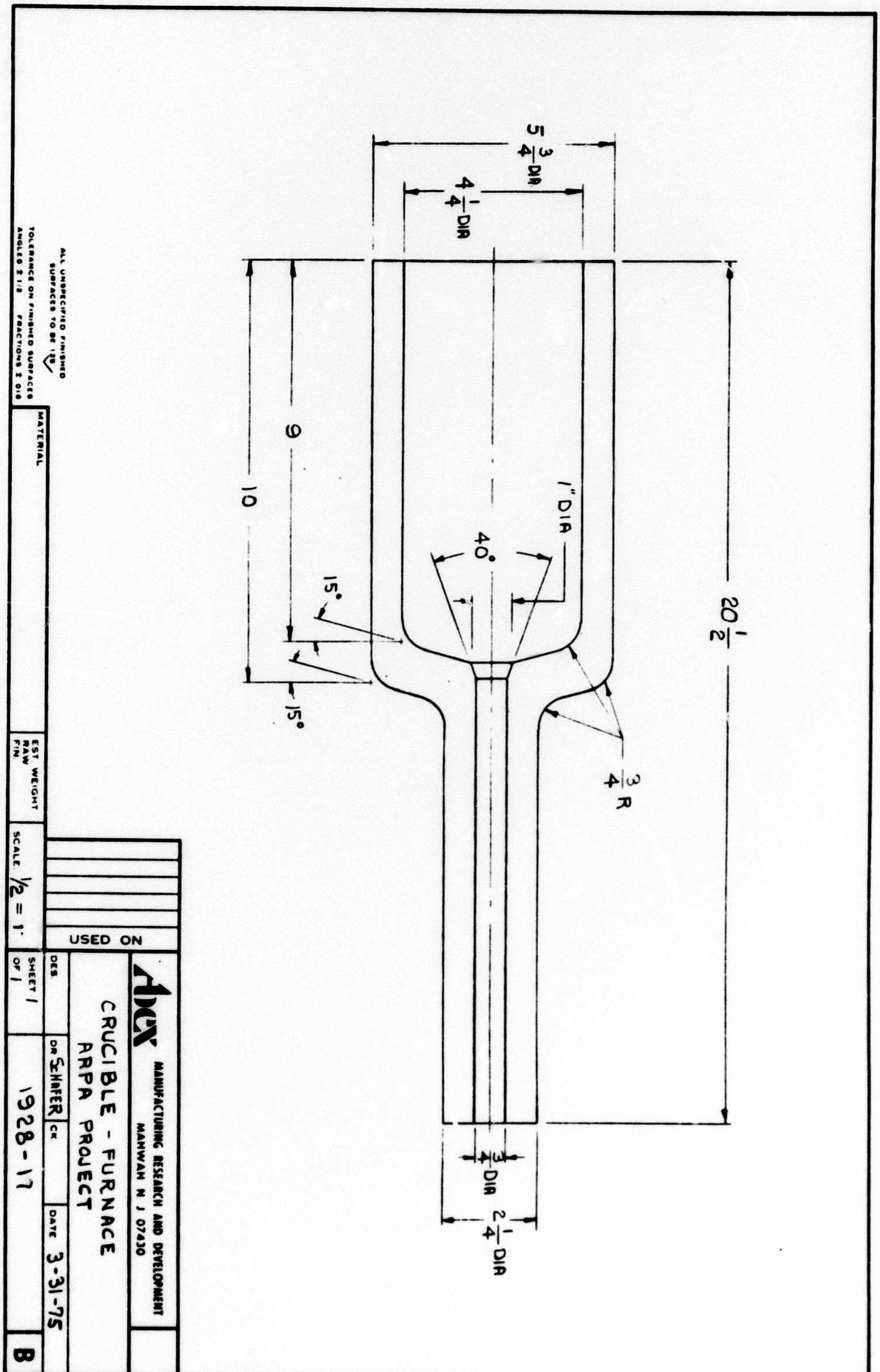
(a) Conventionally Cast



AW116601 50X

(b) Rheocast at about 0.5 solid fraction

Figure 3. Micrographs of conventionally cast and rheocast 356 aluminua base alloy (Al-7% Si).



CRUCIBLE - FURNACE
ARPA PROJECT
MANUFACTURING RESEARCH AND DEVELOPMENT
MAHWAH N J 07430
USED ON
MATERIAL
EST WEIGHT RAW FIN.
SCALE 1/2 = 1
DES.
DR SCHAFER
CK
DATE 3-31-75
SHEET 1 OF 1
1928-17
B
ALL UNSPECIFIED FINISHED SURFACES TO BE 125
TOLERANCE ON FINISHED SURFACES ANGLES ± 1/2 FRACTIONS ± 010
5 3/4 DIA
4 1/4 DIA
20 1/2
10
9
40°
1" DIA
15°
15°
3/4 R
3/4 DIA
2 1/4 DIA

Figure 4

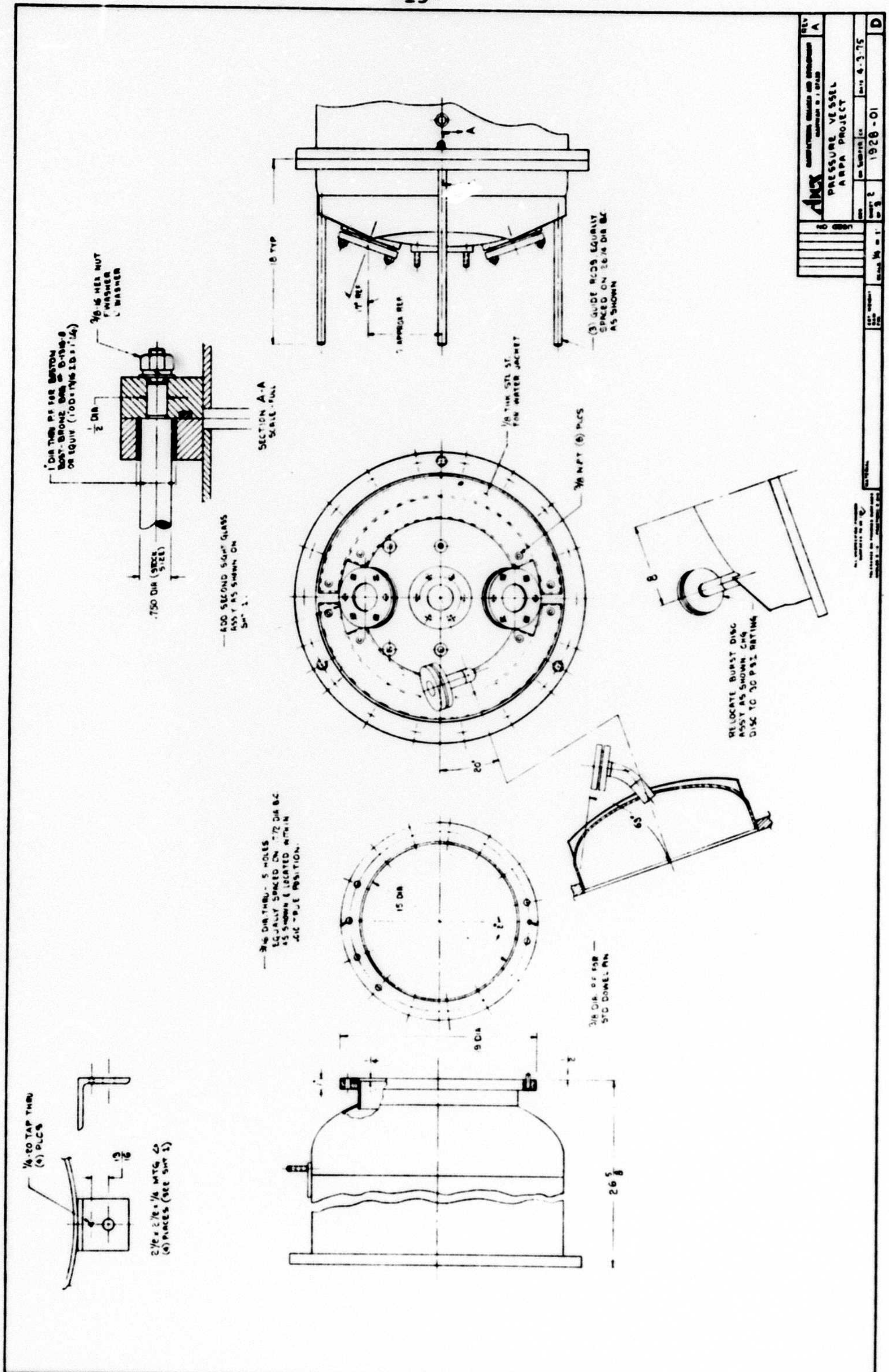
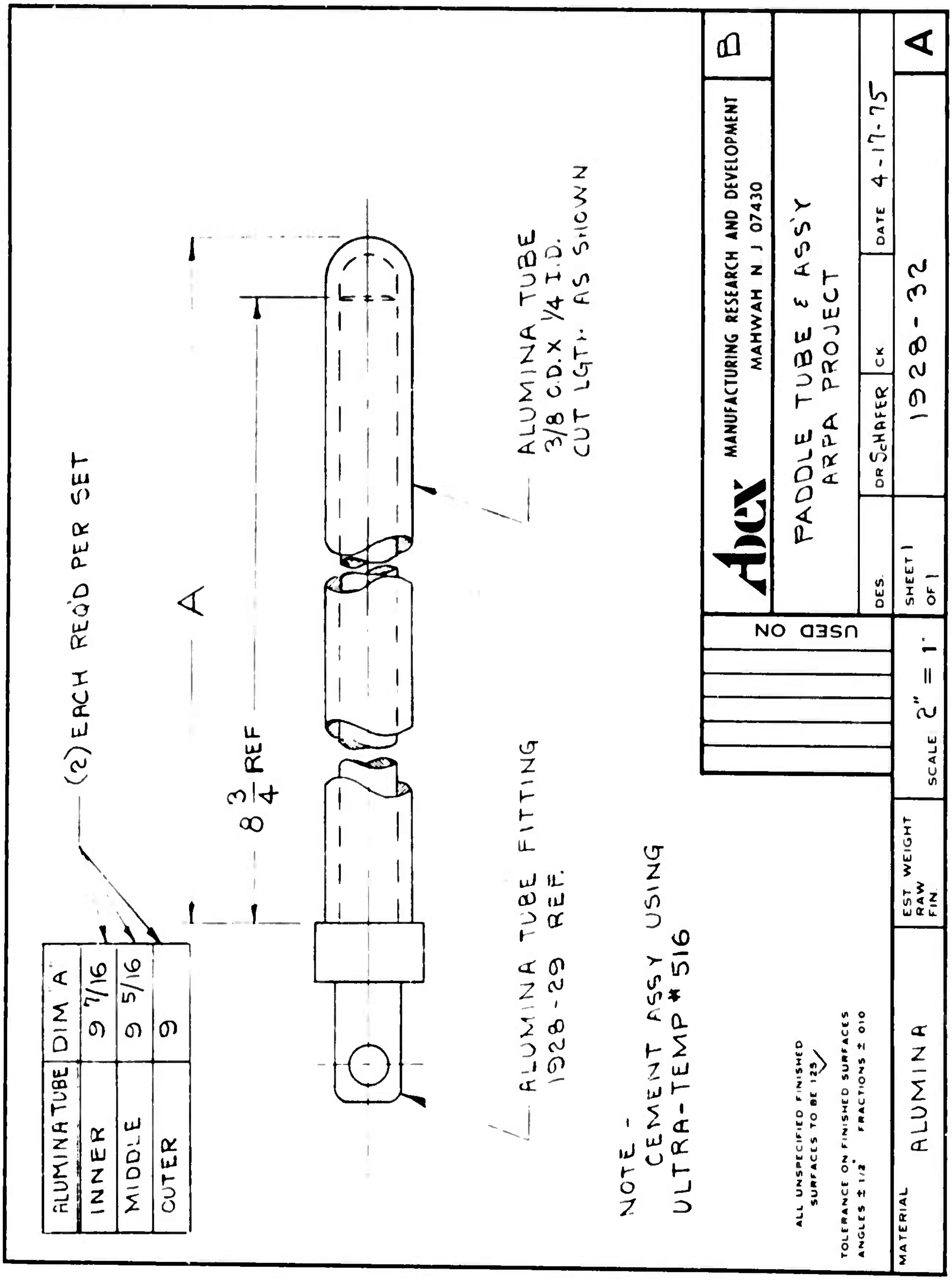


Figure 5


ALUMINA TUBE DIM 'A'
INNER 9 7/16
MIDDLE 9 5/16
OUTER 9
(2) EACH REQ'D PER SET
A
8 3/4 REF
ALUMINA TUBE
3/8 O.D. X 1/4 I.D.
CUT LGTH. AS SHOWN
ALUMINA TUBE FITTING
1928-29 REF.
NOTE -
CEMENT ASSY USING
ULTRA-TEMP # 516
ALL UNSPECIFIED FINISHED SURFACES TO BE 125
TOLERANCE ON FINISHED SURFACES
ANGLES ± 1/2° FRACTIONS ± .010
MATERIAL
ALUMINA
EST. WEIGHT
RAW
FIN.
SCALE 2" = 1"
USED ON
Abex
MANUFACTURING RESEARCH AND DEVELOPMENT
MAHWAH N J 07430
B
PADDLE TUBE & ASS'Y
ARPA PROJECT
DES.
DR SCHAFER
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SHEET 1 OF 1
1928-32
A

Figure 6

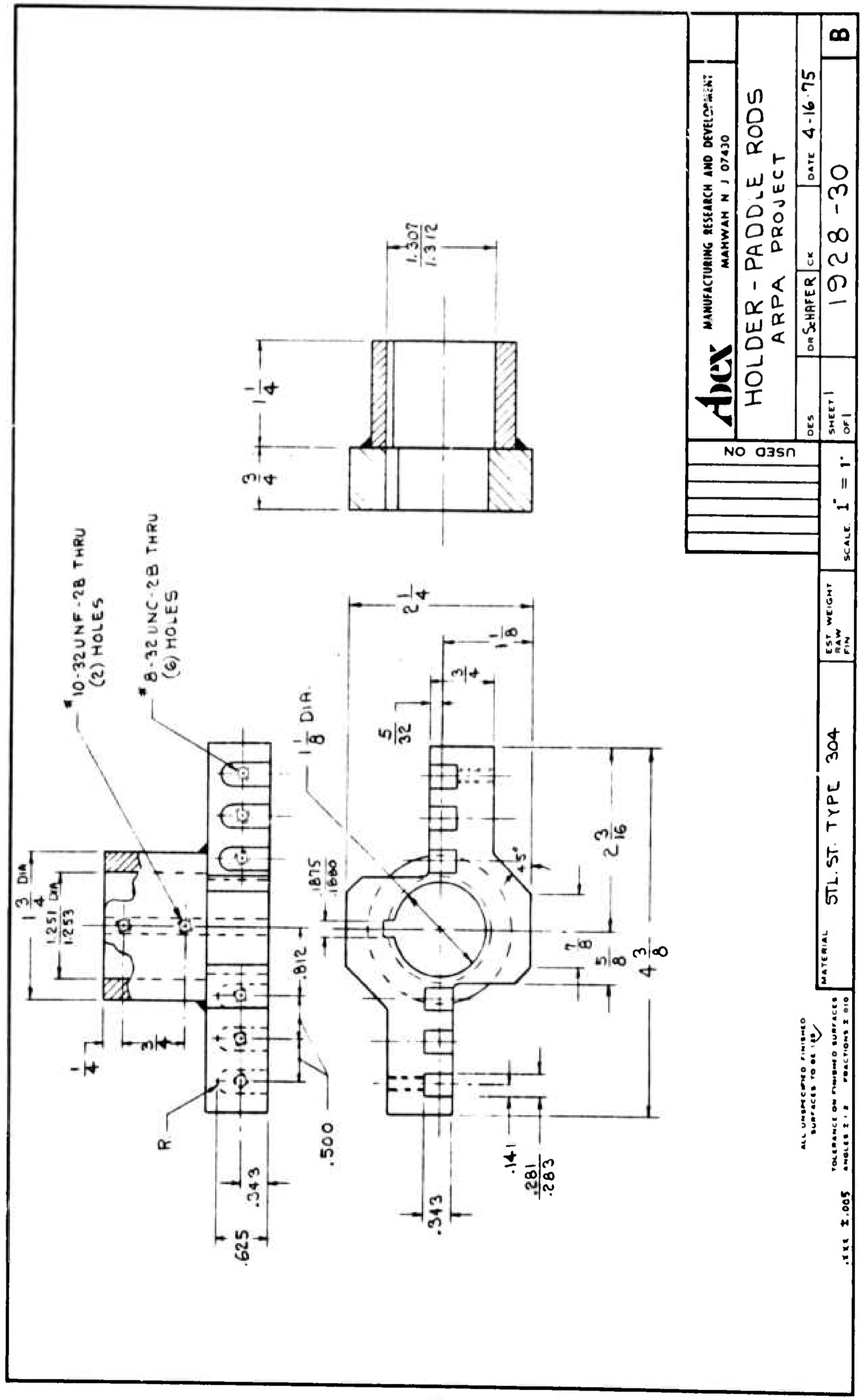
Abex
MANUFACTURING RESEARCH AND DEVELOPMENT
MAHWAH N J 07430
HOLDER - PADDLE RODS
ARPA PROJECT
DR SCHAFER
DATE 4-16-75
1928-30
B
USED ON
SHEET 1 OF 1
SCALE 1" = 1"
MATERIAL STL. ST. TYPE 304
EST WEIGHT RAW FIN
#10-32 UNF-2B THRU (2) HOLES
#8-32 UNC-2B THRU (6) HOLES
1 1/8 DIA.
1 3/4 DIA
1.251/1.253 DIA
1.307/1.312
.1875/.1880
45°
R
.500
.812
.625
.343
.141
.281/.283
4 3/8
2 3/16
2 1/4
TOLERANCE ON FINISHED SURFACES
ALL UNSPECIFIED FINISHED SURFACES TO BE 125

Figure 7

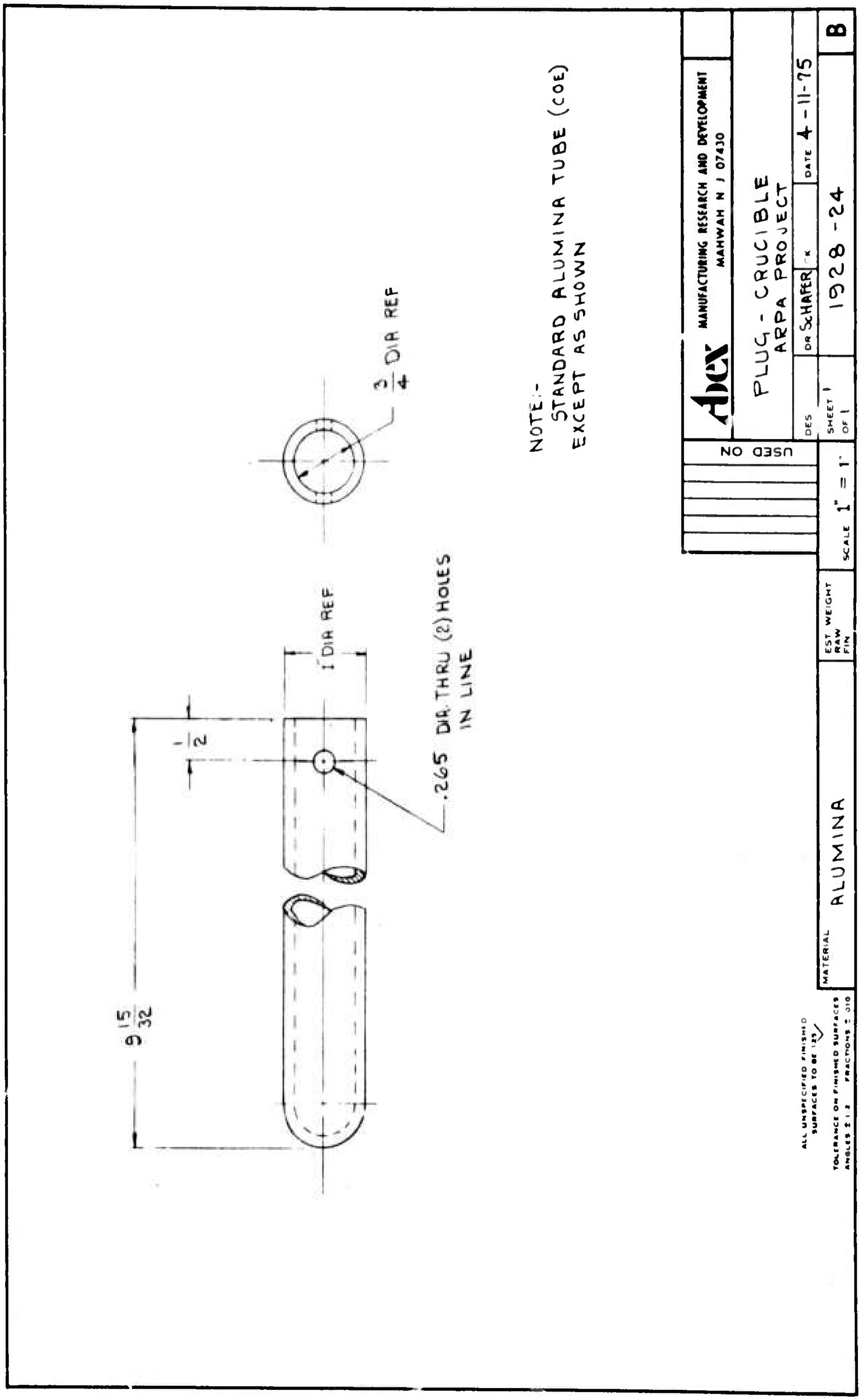
NOTE:-
STANDARD ALUMINA TUBE (COE)
EXCEPT AS SHOWN
3/4 DIA REF
1" DIA REF
.265 DIA THRU (2) HOLES
IN LINE
1/2
9 15/32
Abex MANUFACTURING RESEARCH AND DEVELOPMENT
MAHWAH N J 07430
PLUG - CRUCIBLE
ARPA PROJECT
DES
DR SCHAFER
DATE 4-11-75
SHEET 1 OF 1
1928-24
B
USED ON
SCALE 1" = 1"
EST WEIGHT RAW FIN
MATERIAL
ALUMINA
ALL UNSPECIFIED FINISHED SURFACES TO BE 125
TOLERANCE ON FINISHED SURFACES
ANGLES ± 1/2 FRACTIONS ± .010

Figure 8

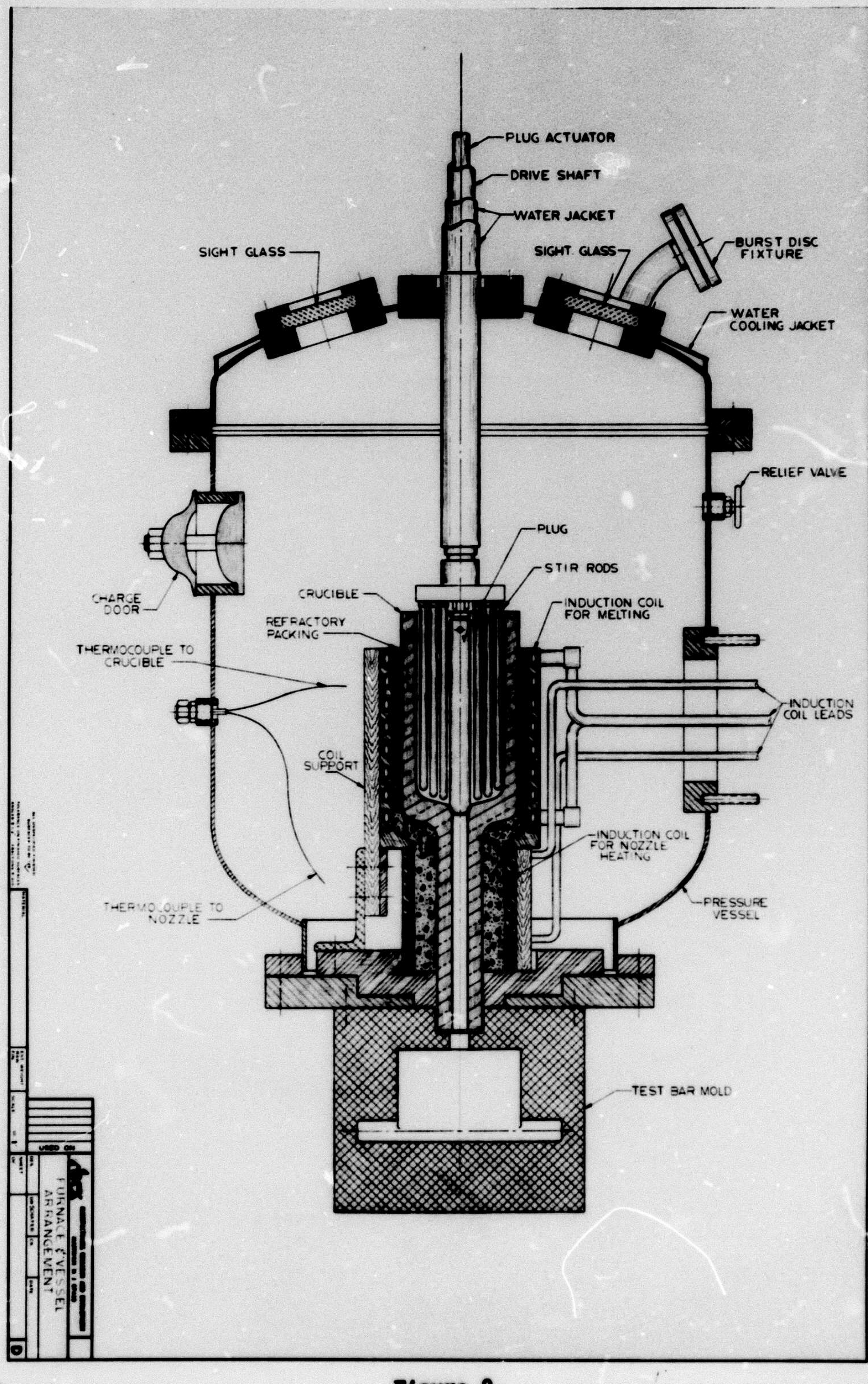
PLUG ACTUATOR
DRIVE SHAFT
WATER JACKET
SIGHT GLASS
SIGHT GLASS
BURST DISC FIXTURE
WATER COOLING JACKET
RELIEF VALVE
PLUG
STIR RODS
CRUCIBLE
INDUCTION COIL FOR MELTING
REFRACTORY PACKING
CHARGE DOOR
THERMOCOUPLE TO CRUCIBLE
INDUCTION COIL LEADS
COIL SUPPORT
INDUCTION COIL FOR NOZZLE HEATING
THERMOCOUPLE TO NOZZLE
PRESSURE VESSEL
TEST BAR MOLD
FURNACE & VESSEL ARRANGEMENT

Figure 9